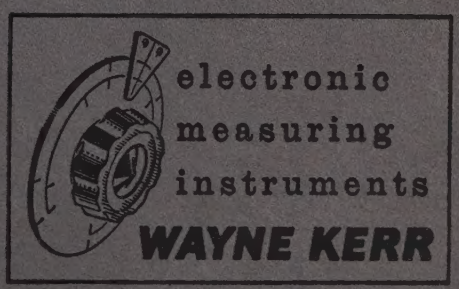
autobalance capacitance bridge

T.G. LAB

G. QUIRK

INSTRUCTION MANUAL

B541



MP MASTER
MA33076

AUTOBALANCE CAPACITANCE BRIDGE

B-541

INSTRUCTION MANUAL

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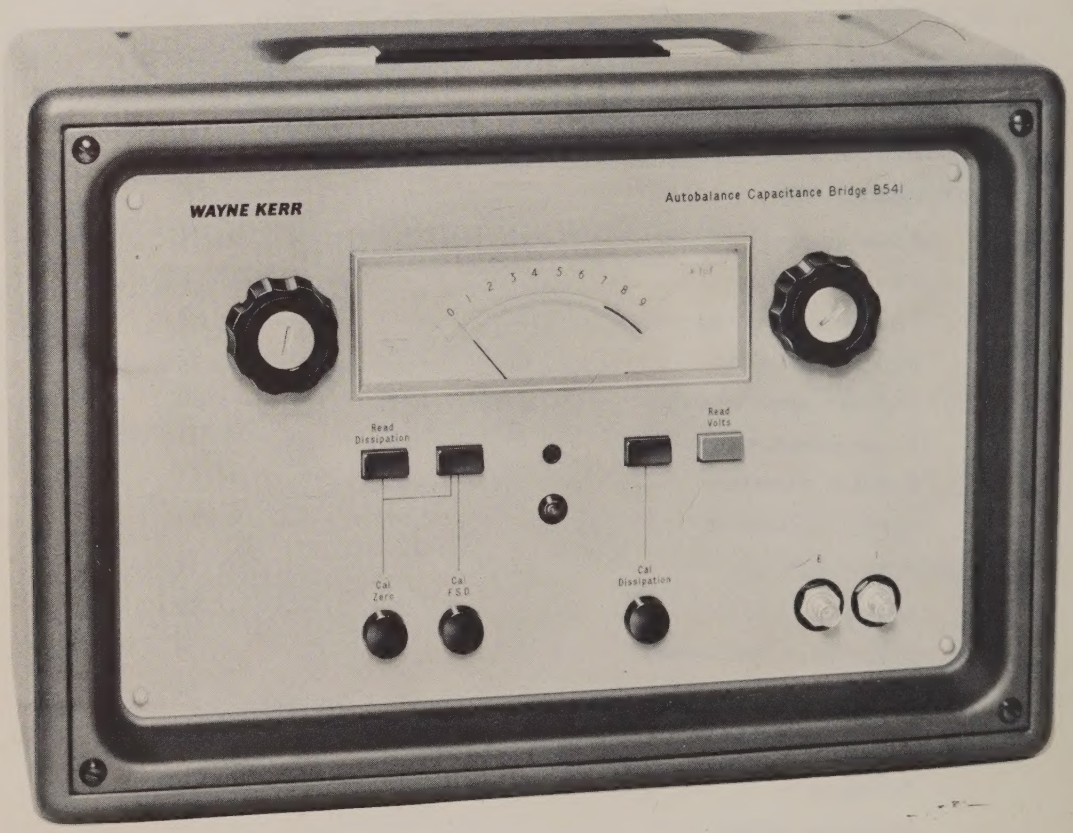


AUTOBALANCE CAPACITANCE BRIDGE B 541

INTRODUCTION

The Autobalance Capacitance Bridge B541 gives a continuous display of capacitance without manual balancing by utilising transformer ratio arm bridge technique modified to incorporate Autobalance features.

A range switch selects any one of the seven capacitance ranges provided for measurements from 0.01$\mu\mu$F to 10μF. A decade switch in the transformer ratio arm bridge circuit incorporated in the instrument functions as a coarse balance control and fine balance is automatically maintained by means of a feedback circuit. The first digit of the capacitance value and the range multiplying factor are displayed in windows beside the meter on the instrument front panel, whilst the second and third digits of the capacitance value are read from the meter.

Facilities for rapid check of the quality of a capacitor by an indication of dissipation are provided.

The wide range of capacitance measurement available and facilities provided for connecting digital voltmeters, limit switches or a recorder make the instrument a useful tool for high speed component batch testing. The bridge output voltmeter is linear with capacitance and can be used to plot temperature coefficients. Varying parameters can be recorded or controlled if the bridge is operated in association with a capacitance transducer thus extending its use to the field of process control.

SPECIFICATION

Capacitance

Range	Accuracy
0 - 10pF	±0.1% ± 0.01pF
0 - 100pF	±0.1% ± 0.1pF
0 - 1000pF	±0.1% ± 1.0pF
0 - 0.01μF	±0.1% ± 0.00001μF
0 - 0.1μF	±0.1% ± 0.0001μF
0 - 1μF	±0.1% ± 0.001μF
0 - 10μF	±0.1% ± 0.01μF

Power Factor

Range 0 - 0.1
Accuracy ±5% ±0.001

Power supply

B541 - 9V battery BU109
B541/P - PS109 for operation from
110V or 200-250V, 50-60 c/s

Dimensions and weight

Width: 17 in. (43 cm).
Height: 11½ in. (29 cm.)
Depth: 7½ in. (19 cm.)
Weight: 25lb. (11 kg.)

OPERATING INSTRUCTIONS

Setting up

1 Insert the measuring leads and link the neutral (green) associated with each lead to the exposed metal sleeve of the other lead.

2 Turn the right hand range switch clockwise from the OFF position (fully anticlockwise) to any other setting.

3 Press the Read Volts button. The meter deflection should lie within the coloured sector below the meter scale. If a deflection outside the coloured sector is obtained, check the PS109 power supply unit or the battery.

4 Set the left hand decade switch to show a digit in the left hand window.

5 Press both left hand buttons whilst adjusting the Cal Zero knob for zero meter reading. Release the buttons.

6 Press the Cal FSD button and adjust the associated control knob for full scale reading on the meter. Release the button.

7 Turn left hand decade switch fully counter-clockwise.

Capacitance measurement

8 Connect the capacitor to be measured to the inner leads from sockets E and I on the B541 and proceed as follows:

(1) Select the appropriate range for a meter reading greater than 1. The range multiplier appears in the right hand window.

(2) Transfer the first digit of the meter reading to the decade by means of the left hand control knob. The decade reading appears in the left hand window.

(3) Read capacitance. For example, if:

Decade reading is 2.

Range multiplier is 100pF.

Meter reading is 3.4 showing that the second and third digits of the capacitance value are 3 and 4.

Capacitance = (2.34) x 100pF = 234pF.

Dissipation measurement

9 Press Cal Dissipation button and adjust the associated control knob for full scale reading of the meter. Release the button.

10 Press the Read Dissipation button and read the meter, ignoring the decade reading. The meter range is 0 - 0. 1.

Notes:

(1) If the measurement of capacitance is to be made without using the decade, operations 4 to 6 above are carried out with the decade switch S2 in the fully counter-clockwise position.

(2) Dissipation can be checked only when the correct range and decade for the capacitance under test have been selected.

(3) For monitoring outputs available with a B541/R, instructions for connecting a recorder panel RP541 to a B541 and operation of the instrument as a differential bridge see pp. 15 to 18.

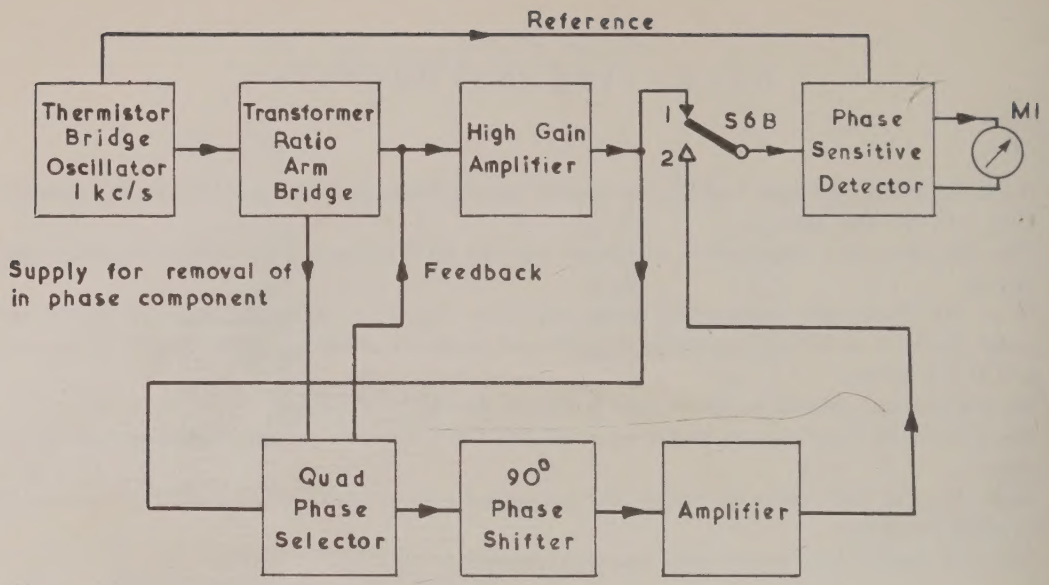


Fig. 2. Block Schematic

PRINCIPLE OF OPERATION (fig. 2)

The basic element of the B541 is a transformer ratio arm bridge[1] fed by a 1kc/s oscillator; the unknown capacitance and a standard known capacitance are connected in the bridge and its output is fed to a high gain, negative feedback amplifier to provide an automatically balancing system.[2]

Approximate capacitance measurements are made by feeding the output of the high gain amplifier through a phase sensitive detector (switch contact S6B in position 1), which rectifies the in phase[+] component of the amplifier output but not its quadrature component[+]. Meter M1 therefore displays the in phase component of the amplifier output, the range switch of the transformer ratio arm bridge being set to give an on scale deflection. The meter deflection is proportional to the unknown capacitance.

The meter cannot indicate accurately three significant figures. Accurate capacitance measurements are therefore made by first using the decade switch of the transformer ratio arm bridge to balance the unknown against the known capacitance approximately. The output of the transformer ratio arm bridge is then a signal which is dependant upon the difference between the total unknown capacitance and that part balanced manually by means of the decade switch. Under these conditions, the decade switch setting indicates the first digit and meter M1 indicates the second and third digits of the unknown capacitance value, see Appendix 2, p.22.

The quality of the unknown capacitor is determined by first adjusting the high gain amplifier output so that its in phase component gives full scale deflection of meter M1 and then indicating the quadrature component of the output on the meter. The quadrature component is fed to meter M1 by applying the high gain amplifier output to circuits which remove the in phase component, phase shift the quadrature component by 90° to bring it in phase with the transformer ratio arm bridge source, amplify this signal and feed it through the phase sensitive detector to the meter (switch contact S6B in position 2). The meter therefore indicates the ratio of the quadrature to the in phase component and is calibrated to read tan δ directly.

1 See Wayne Kerr Monograph No.1 'The Transformer Ratio Arm Bridge' by Raymond Calvert.
2 See 'Self-balancing Transformer Ratio Arm Bridge' by R. Calvert and J. Mildwater.

\+ Quadrature component and in phase component referred to the 1kc/s bridge source.

CIRCUIT DESCRIPTION (circuit diagram)

The circuit comprises a power supply, 1kc/s oscillator, transformer ratio arm bridge, high gain amplifier, and phase sensitive detector. Circuits are also incorporated for removal of the in phase component of the high gain amplifier, and phase shifting and amplifying the remaining quadrature component.

Power supply

B541/P contains a PS109 power unit which is designed to operate with a 200V to 250V a.c. supply when the two primary windings on the transformer T1 are connected in series by joining taps 2 and 3 together. A 110V supply can be used if the two primary windings of T1 are connected in parallel by linking tap 1 to tap 2 and tap 3 to tap 4.

The power supply is switched on by turning the right hand range switch from the fully anticlockwise position to any other position. One end of the primary winding of T1 is then connected, through switch section S1A, to the neutral line to complete the input circuit.

The rectified and smoothed output of the secondary winding of transformer T1 is stabilised by transistor VT1, which is connected as a series regulator in the d.c. line with VT3, VT4 operating as parallel control transistors. The base potential of VT4 is adjusted by preset resistor RV1 and its emitter is maintained at a constant potential by zener diode MR1. Changes in the d.c. supply are amplified by VT4 and VT3 and passed to the base of VT1 through emitter follower VT2. Transistor VT1 regulates the PS109 output voltage to provide a stable 9V potential for the bridge circuits.

The B541 instrument contains a battery which provides the 9V supply.

1 kc/s oscillator

A thermistor bridge oscillator circuit is used as the source for the transformer ratio arm bridge. The oscillator stage (VT3) is fed by the bridge circuit which comprises the centre tapped secondary winding, SEC3, of the voltage transformer, T2, thermistor TH1 and resistor R9. The bridge is balanced when the resistances of TH1 and R9 are equal. Changes in voltage are compensated by the action of the thermistor. Frequency compensation is provided by variable resistor RV1 and capacitor C5.

The thermistor bridge output is amplified by transistor VT1 and fed to the base of the oscillator stage VT3 through emitter follower VT2. The collector load of VT3 is an auto transformer T1 tuned to 1 kc/s by capacitor C4. Neon N1 lights up to indicate that the instrument is switched on.

The frequency of the thermistor bridge oscillator circuit is set to 1 kc/s ±0.25 per cent at production by adjusting the movable slug in the autotransformer T1. The Cal Zero control RV1 is used to trim the oscillator frequency and thus adjust the phase shift in the dissipation circuit provided for removal of the in phase component of the amplifier output, see p.12.

The oscillator circuit feeds a stable 1 kc/s signal to the transformer ratio arm bridge and has a low output impedance and a temperature coefficient of approximately 0.2 per cent per degree centigrade. The load of the unknown and its associated shunt loading have negligible effect and the oscillator output is sufficiently free from harmonics to prevent spurious indication from the phase sensitive detector.

Transformer ratio arm bridge

Toroidal windings on cores of very high permeability nickel iron alloy are used for the voltage and current transformers of the bridge and a core geometry which minimises error flux linkages. The design gives very low ratio errors between windings of the transformers and a minimum winding leakage impedance. The current transformer shunt impedance provides a high input impedance to the amplifier fed by the bridge output. Analysis of the self balancing transformer ratio arm bridge[2] shows these factors to be of importance for overall accuracy of the system.

The unknown capacitor is connected between the inner leads from the B541 F and I sockets. The standard capacitor C6 is preset to 0.01μF by capacitor C7. Preset capacitor C8 adjusts the circuit for stray capacitance through the bridge. Where a comparator capacitance standard is used, it is connected to the transformer windings of the bridge through recorder panel RP541, see p. 15

The range switch S1 has two sections, S1B and S1C which select appropriate tappings on the voltage and current transformers for the range of capacitance measurement required. A multiplying factor, which depends upon the setting of the range switch, appears in the right hand window of the instrument front panel. The value indicated by the decade and meter readings is multiplied by this factor to obtain the unknown capacitance. The following table lists the tappings and multiplying factors for the seven ranges of the instrument.

Range switch position (from fully clockwise)	Voltage transformer tap	Current transformer tap	Range	Multiplying factor
2	1, 000	1, 000	0-10pF	x1pF
3	100	1, 000	0-100pF	x10pF
4	100	100	0-1000pF	x100pF
5	10	100	0-0.01μF	x0. 001μF
6	10	10	0-0.1μF	x0. 01μF
7	1	10	0-1.0μF	x0. 1μF
8	1	1	0-10μF	x1. 0μF

The decade switch has four sections S2A, S2B, S2C, S2D, which select tappings on the voltage and current transformer. Switch S2D selects the decade and the other sections are used to adjust the sensitivity of the bridge.

High gain amplifier

The output of the transformer ratio arm bridge is coupled through the primary winding PR1 of the current transformer T4 to the input of the three stage (VT4, VT5, VT6), high gain amplifier. The input is amplified by transistor VT4, and the signal at the collector of the transistor is capacitance resistance coupled to the following 90° phase shifter stage (VT5). The phase shift is provided by feedback from the collector of VT5 to its base through capacitor C14, the feedback current being advanced 90° on the voltage. The output at the collector of VT5 is coupled directly to the base of transistor VT6.

The collector of transistor VT6 is loaded by autotransformer T5, which is tuned to 1 kc/s by capacitor C16. In the absence of the tuned circuit, the response of the amplifier would be flat over the audio frequency band. The high Q tuned circuit of the final amplifying stage inserts a peak at 1 kc/s thus giving maximum signal to noise ratio. The output of the tuned stage is capacitance resistance coupled to emitter follower VT7, which provides a low impedance output.

High gain amplifier output

The output of the high gain amplifier from the emitter of VT7 is:

(1) fed through the capacitor C26 and the resistor chain R40, R41, R42, RV4, RV5. Feedback from the output of the high gain amplifier is taken from this resistor chain through double emitter follower VT14, VT15, feedback element C9 and winding SEC3 of the current transformer T4 to the input of the amplifier. For example, with the circuit set for capacitance measurements, i.e. with no switches depressed, the feedback path is through C26, R40, switch contacts S6D, S5A, VT14, VT15, capacitor C9, switch contacts S6A, S5B and decade switch section S2B to the 10 turn or the 100 turn tapping of SEC3. The flux set up in the current transformer T4 by the feedback current is in such a sense as to oppose the flux set up by the current through the unknown and standard capacitors.

(2) fed directly to the phase sensitive detector circuit (VT9, VT10) through switch contacts S6B and emitter follower VT8 for capacitance measurements, i.e. with the Read Dissipation switch S6 unoperated.

(3) fed from the collector of VT13 through switch contacts S6B and emitter follower VT8 to the phase sensitive detector for dissipation measurements, i.e. with the Read Dissipation switch S6 depressed. The signal at VT13 is the 90° phase shifted amplified quadrature component of the amplifier output, see p. 14.

Phase sensitive detector

The transistors VT9 and VT10 are connected as bi-directional switches in a phase sensitive detector circuit. Gate signals are fed to the transistor bases from the two halves of the centre tapped winding SEC3 of the voltage transformer T2. The switching waveform opens and closes the switches in phase with the supply to the voltage transformer. The switches are thus, effectively, either a short circuit or open circuit compared with the meter resistance and the transistor parameters have very little effect on the performance of the circuit.

When capacitance measurements are made, with the Read Dissipation switch S6 unoperated, the in phase component of the amplifier output is rectified by the phase sensitive detector circuit and the meter M1 gives a linear indication of the average value of the rectified waveform. Phase reversal is indicated by a reversal of the meter indication to give an off scale reading below zero. There is, effectively, no rectification of the quadrature component of the amplifier output, this component being reduced by better than 40 db by the phase sensitive detector circuit.

In the case of dissipation measurements, i.e. with the Read Dissipation switch depressed, the phase shifted amplified, quadrature component of the high gain amplifier output is rectified to give a linear indication of the average value of this component on meter M1.

Overload protection

Spurious on scale meter readings due to overload conditions in the high gain amplifier are prevented by an overload protection circuit which is fed by the tuned stage (VT6) of the amplifier. The circuit comprises diodes MR1, MR2, transformer T6 and resistor R31. Overload conditions which cause the diodes to conduct give an off scale meter M1 reading greater than full scale deflection.

Dissipation circuits

The dissipation circuits perform the following functions:

(1) Remove the in phase component: Preset control RV4 is adjusted at production so that the potential across the network comprising capacitor C26, resistors R40, R41, R42, potentiometers RV4 and RV5, due to the component of the high gain amplifier output which is in phase with the 1kc/s source, is equal and opposite to the output from winding SEC1 of the voltage transformer T2. The in phase component of the high gain amplifier output is therefore reduced to zero.

(2) Apply a 90° phase shift to the quadrature component: The quadrature component of the high gain amplifier output is fed to the 90° phase shift network, capacitors C23, C24 and resistors R38, R39. The output from this network is adjusted at production by RV3 to be in phase with the 1 kc/s bridge source.

(3) Amplify the phase shifted quadrature component: The signal from the phase shift network is fed through emitter follower VT11 to the amplifier comprising transistors VT12, VT13 and their associated components. The amplifier has a gain of 10. With switch S6 (Read Dissipation) depressed, the supply from the high gain amplifier to the phase sensitive detector (VT9, VT10) is replaced by the phase shifted and amplified quadrature component fed from the collector of VT13 through switch contact S6B and emitter follower VT8. The meter M1 indication is therefore proportional to the quadrature phase component of the high gain amplifier output.

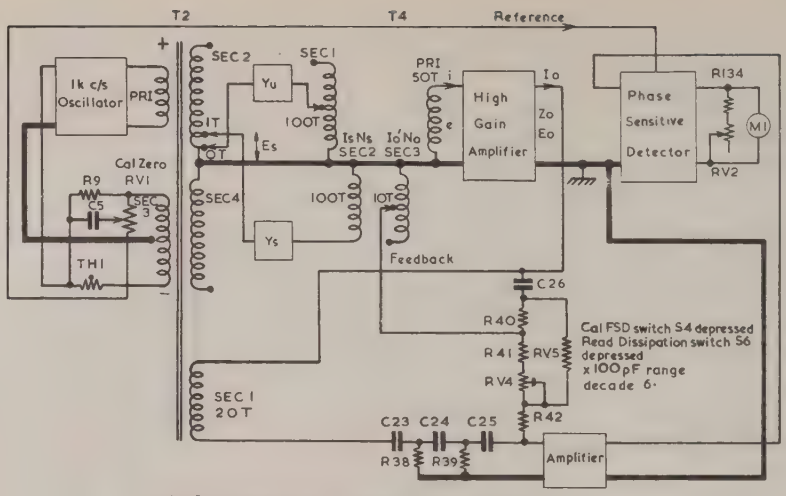


Fig.3a Dissipation circuit phase trim.

CIRCUIT OPERATION

Setting up(fig. 3)

The h.t. volts are checked by pressing switch S3 (Read Volts) on the instrument front panel. Switch contacts S3A and S3B then change over to connect the supply voltage across indicator M1.

The instrument is set up by making the following adjustments:

(1) The phase shift in the dissipation circuit, provided to remove the in phase component of the high gain amplifier output, is trimmed by slightly adjusting the frequency of the 1kc/s source to match the detector frequency using the Cal Zero control RV1. The range switch is set to show a multiplying factor in the right hand window and the decade switch adjusted as required, see operating instruction 4 and note (1), p.7. The Cal FSD switch S4 and the Read Dissipation switch S6 are depressed whilst RV1 is adjusted to reduce the in phase component of the high gain amplifier output (applied to meter M1 through the dissipation circuits and the phase sensitive detector) to zero, i.e. until meter M1 reads zero. Fig. 3a shows the circuit conditions with the decade and range switches set to display 6· in the left hand window, the x 100 pF multiplying factor in the right hand window and with switches S4 and S6 depressed.

(2) The meter sensitivity is adjusted with switch S6 released but with the other circuit conditions unchanged. The high gain amplifier output is now applied to meter M1 directly through the phase sensitive detector. The output of the detector is adjusted by the Cal FSD control RV2 so that the in phase component of the high gain amplifier output gives full scale meter deflection. Fig. 3b shows the circuit conditions with the decade and range switch settings unchanged and switch S4 depressed.

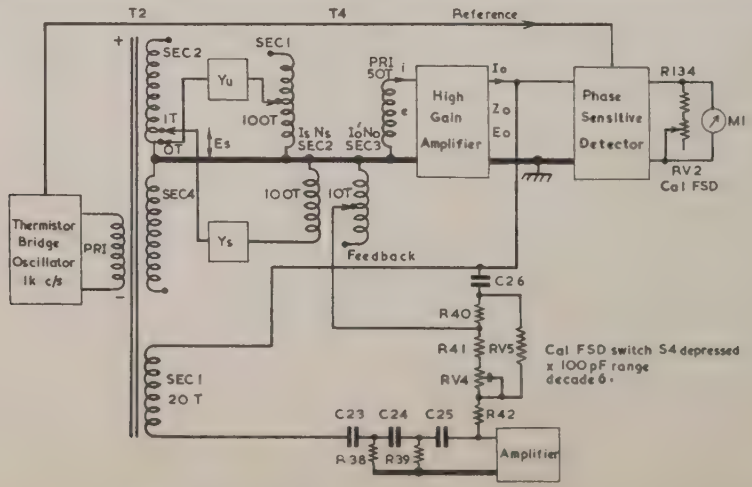


Fig.3b Adjustment of meter sensitivity

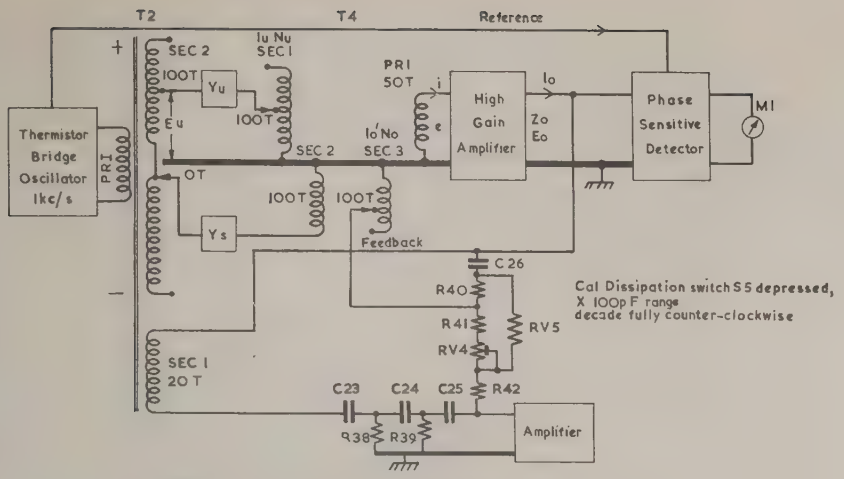


Fig.4a Approximate capacitance measurement on meter M1

Capacitance measurement (fig. 4)

The measurement of capacitance is carried out in two stages.

(1) Approximate measurement of capacitance is made with autobalance and no decade, i.e. with decade switch S2 fully counter clockwise. Suppose the capacitance to be measured is such that, to obtain a meter reading on scale, the range switch S1 has to be set to show a x 100pF multiplying factor in the right hand window, see fig. 4a. The ampere turns in winding SEC1 of current transformer T4 are balanced by the ampere turns in feedback winding SEC3 of T4. If the meter reading is approximately 6.45, the capacitance value is approximately 645$\mu\mu$F, see Appendix 2.2, p.22.

(2) Accurate measurement of capacitance is made using the decade and autobalance. The decade switch is set to show 6· in the left hand window, i.e. the first digit of the approximate value of the capacitance, with the x 100pF multiplying factor still displayed in the right hand window, see fig. 4b. The ampere turns in feedback winding SEC3 of current transformer T4 balance the ampere turns in winding SEC1 and SEC2 of T4. The second and third digits of the unknown value can now be read accurately on meter M1. Suppose, for example, that meter M1 registers 4.3 showing that the digits are 4 and 3. The accurate value of the unknown capacitance in this case is 643$\mu\mu$F, see Appendix 2.3, p. 23.

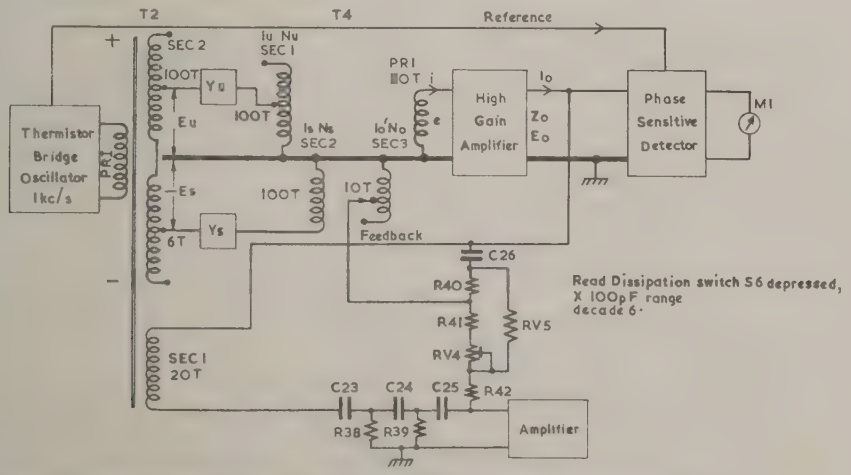


Fig.4b Accurate capacitance measurement using decade and meter M1

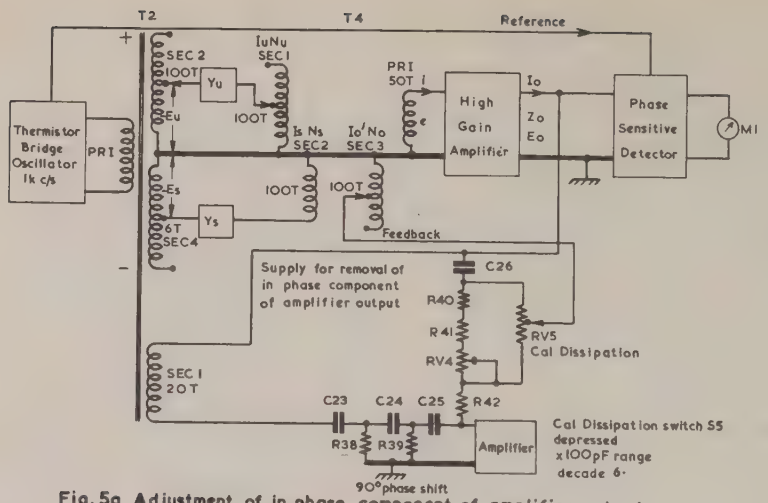


Fig. 5a Adjustment of in phase component of amplifier output.

Dissipation measurement (fig. 5)

There are two stages in the measurement of dissipation which are performed with the range switch S1 and decade switch S2 at the settings required for capacitance measurement, i.e. in the example chosen, to show a x 100pF multiplying factor and a 6·decade digit.

(1) The feedback is adjusted by means of the Cal Dissipation control RV5 to produce a phase sensitive detector output which will give full scale deflection on meter M1. During this operation, switch S5 (above the Cal Dissipation control) is pressed to route the feedback signal through the Cal Dissipation control RV5 as shown in fig. 5a.

(2) The meter M1 gives a reading proportional to the quadrature component of the high gain amplifier output when switch S5 is released and switch S6 (Read Dissipation) is pressed. The quadrature component is separated from the in phase component, phase shifted by 90°, amplified and fed to M1 through the phase sensitive detector, see fig. 5b. M1 indicates the ratio of the quadrature phase component to the in phase component thus giving tan δ for the capacitance under measurement. Preset control RV6 is adjusted at production to give full scale deflection of M1 for a power factor of 0.1.

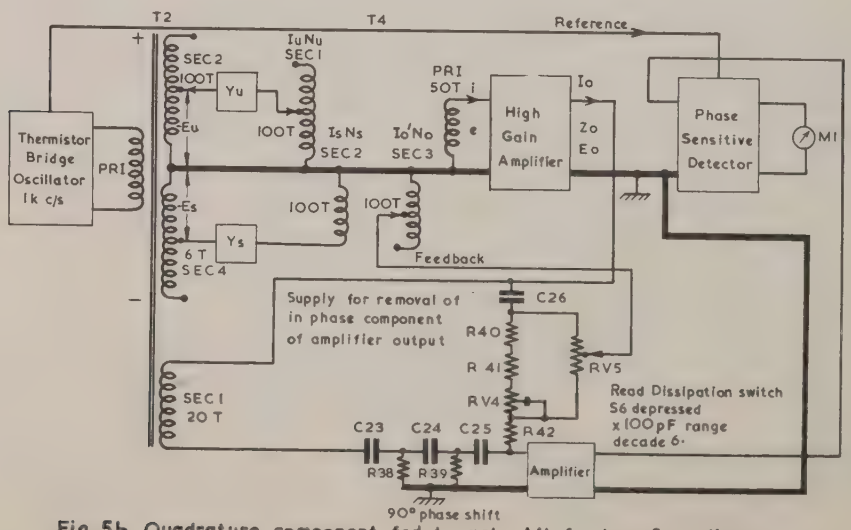


Fig. 5b Quadrature component fed to meter MI for tan δ reading.

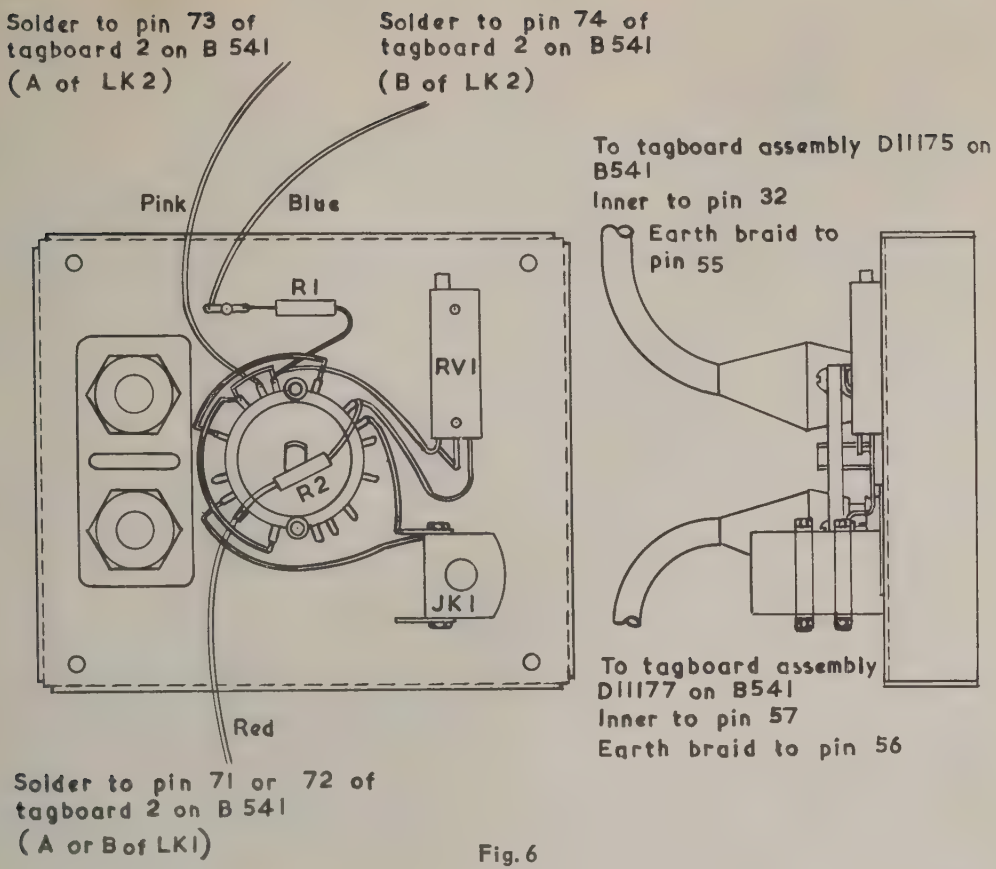

Solder to pin 73 of tagboard 2 on B 541 (A of LK2)
Solder to pin 74 of tagboard 2 on B541 (B of LK2)
To tagboard assembly D11175 on B541 Inner to pin 32
Earth braid to pin 55
Pink
Blue
R1
RV1
R2
JK1
To tagboard assembly D11177 on B541 Inner to pin 57 Earth braid to pin 56
Red
Solder to pin 71 or 72 of tagboard 2 on B 541 (A or B of LK1)

Fig. 6

RECORDER PANEL RP 541 (fig. 6)

B541/R capacitance bridge is fitted with a recorder panel RP541. The recorder panel can also be supplied as a separate item.

The RP541 is designed to feed the bridge output to an external voltmeter, limit switch or recorder. Sockets E (SK1) and I (SK2) are also provided on the panel for connection of an external comparator standard for differential measurements.

Setting up

The panel layout is given in fig. 6, which shows the red, blue and pink leads and the leads from the E and I sockets on the panel. The RP541 is connected as follows:

(1) Disconnect link LK2 in the B541 circuit.

(2) Remove the 22K resistor R58 connected across meter M1, if fitted.

(3) Solder the red lead from the RP541 to pin 71 or 72 of tagboard 2 on the B541.

(4) Solder the blue lead from the RP541 to pin 74 of tagboard 2 on the B541.

(5) Solder the pink lead from the RP541 to pin 73 of tagboard 2 on the B541.

(6) Solder the inner of one screened lead from the sockets E and I on the RP541 to pin 32 on tagboard assembly on D11175 and the earth braid to pin 55 of the same tagboard assembly on the B541.

(7) The other screened lead is connected similarly, the inner to pin 57 and the earth braid to pin 56 on tagboard assembly D11177 on the B541.

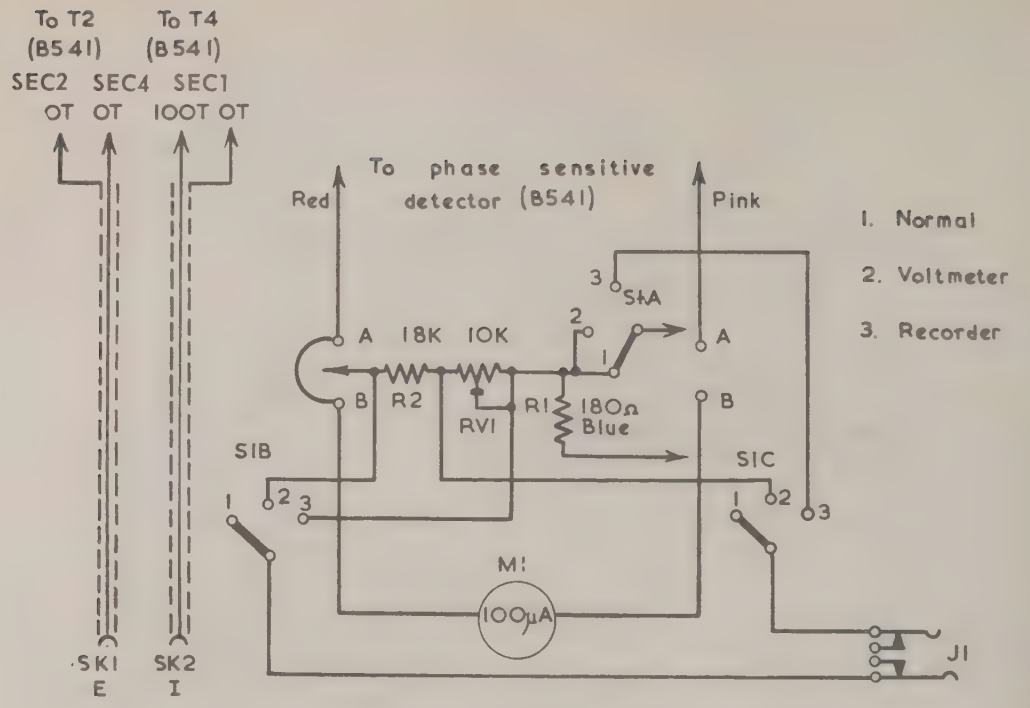


Fig. 7a Circuit (RP541)

Monitoring outputs (fig. 7)

The circuit of the RP541 is given in fig. 7a, and fig 7b shows the connections at each setting of the switch S1. There are three positions of S1 as follows:

(1) **Normal**: Capacitance values are read using the B541 decade and meter M1 with no external output at jack J1.

(2) **Voltmeter**: An output of 100mV is available at jack J1 for operating an external voltmeter having not less than 2.2 megohms resistance. RV1 is adjusted, with the external voltmeter connected, to give agreement between the B541 meter M1 and the external meter.

(3) **Recorder**: An output of 100μA is available at jack J1 for operating an external recorder having a resistance not greater than 100 ohms. RV1 is adjusted to give agreement between the B541 meter M1 and the external recorder.

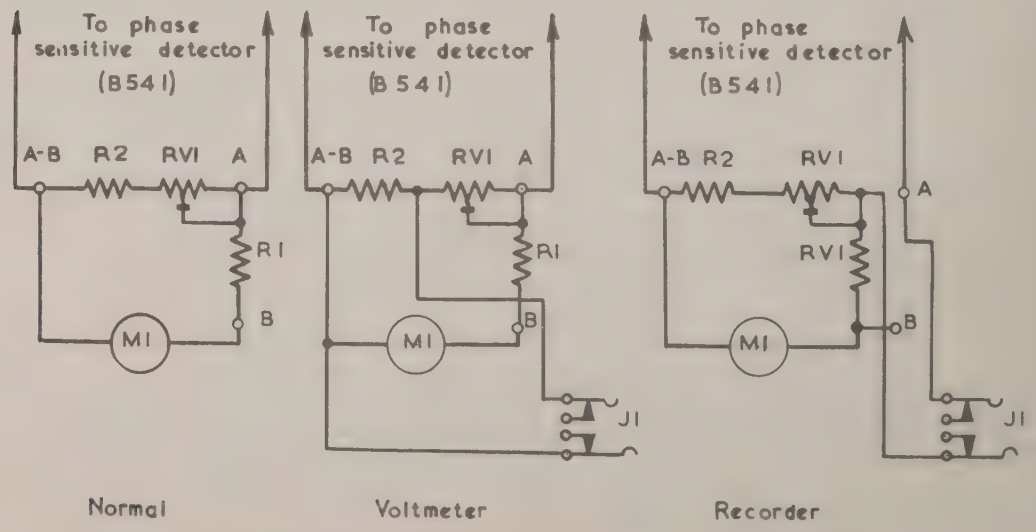


Fig. 7b Monitoring outputs (RP541)

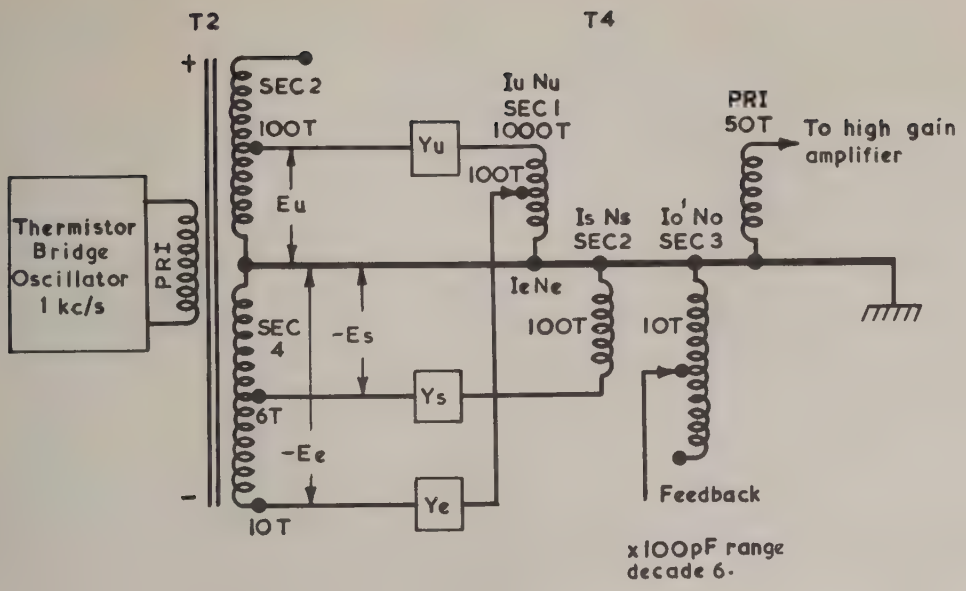


Fig. 8. Differential measurements

B541 as differential bridge or comparator (fig. 8)

An external capacitor C_e (admittance Y_e), fitted between the inner leads from sockets E and I on the control panel RP541, is connected into the B541 circuit as shown in fig. 8, i.e. between the 10 turn tapping on the negative voltage winding of transformer T2 and the 100 turn tapping on winding SEC1 of the transformer T4. Thus the resultant ampere turns in winding SEC1 of T4 depends upon the difference between the admittance Y_e and the admittance Y_u of a capacitor C_u, connected between the inner leads from sockets E and I of the B541. The B541 therefore becomes a differential bridge or comparator and variations in the value of a capacitance can be recorded, e.g. for temperature coefficient measurements, or a small difference between two large capacitors of nominally the same capacitance can be measured.

Use of the B541 to measure small variations in capacitance

If an unknown capacitance C_u is first measured in the normal manner, it is possible to use column 3 of the table in Appendix 3, p.23, to calculate the value of external standard capacitance C_e required to obtain a centre scale reading (5), without decade, on a range of higher sensitivity than that used for normal measurement. The following table is derived from the table of Appendix 3 and gives formulae for calculating the value of C_e.

Range	Scale deflection	Ce(μF) for centre scale (5) meter deflection (without decade)
x 1 pF	0 to 10 pF	1000 C_u - 0.005
x 10 pF	0 to 100 pF	100 C_u - 0.005
x100 pF	0 to 1000 pF	10 C_u - 0.005
x 0.001μF	0 to 0.01 μF	1 C_u - 0.005
x 0.01 μF	0 to 0.1 μF	0.1 C_u - 0.005
x 0.1 μF	0 to 1.0 μF	0.01 C_u - 0.005
x 1 μF	0 to 10 μF	0.001C_u - 0.005

Small variations in value of the capacitance C_u can then be measured, e.g. ±5pF on the x1pF range.

For example, it is required to measure small variations in the value of a capacitor of nominal value 0.053μF. This value of capacitance is measured in the normal manner on the x 0.1μF range. By using the x100pF range and a capacitor C_e of value:

$$C_e = [(10 \times 0.053) - 0.005] = 0.525\mu F$$

variations of ±500pF in the value of C_u can be observed. Similarly, by using the x10pF range and a capacitor C_e of value:

$$C_e = [(100 \times 0.053) - 0.005] = 5.295\mu F$$

variations of ±50pF in the value of C_u can be observed.

The decade can be used in the normal way to increase the accuracy of reading the variations in the value of C_u.

Use of the B541 as a comparator

From the table above it is seen that comparison between a capacitor C_u and an external capacitor C_e having similar values can be made using the x0.001μF range. The sensitivity of the x0.001μF range is suitable for comparison of capacitors of value 10000pF and upwards.

NOTE: Only the neutrals of the pair of leads connecting the unknown capacitance C_u to the bridge or the neutrals of the pair of leads connecting the external standard to the RP541 should be connected together.

MAINTENANCE

The B541 bridge circuits can be checked, as required, by following the instructions given below.

D.C. supply

(1) Turn the right hand (range) switch clockwise from the off position to any other setting. The meter should read within the coloured band below its scale.

A low battery voltage or faulty power supply PS 109 will result in readings outside the coloured band. If the instrument is supplied by a battery, the battery should be replaced. If power supply is by an a.c. driven PS 109, check the series regulator VT 1 (OC 205) and parallel control transistors VT3 (OC 305/2) and VT4 (OC 201).

Voltages

(2) Loosen the four fixing screws on the instrument front panel and withdraw the instrument from its case.

The location of a fault in the bridge circuits can be determined by checking the transistor potentials against the values shown in the following table. The d.c. voltages quoted in the table are typical and deviations up to about 20 per cent do not necessarily indicate a fault. Use a voltmeter having a resistance of 20,000 ohms per volt, e.g. an Avo 8.

Transistor	Voltages	
	Emitter	Collector
VT1	1.85	3.75
VT2	3.75	8.6
VT3	0.5	8.6
VT4	0.8	3.0
VT5	0.85	2.5
VT6	2.75	6.6
VT7	3.45	8.3
VT8	3.3	8.3
VT11	4.0	8.3
VT12	0.85	2.1
VT13	2.4	4.55
VT14	4.0	8.2
VT15	8.25	4.0

Oscillator frequency and amplitude

(3) Set the Cal Zero control RV1 to its mid position.

(4) If necessary, adjust the movable slug in the autotransformer T1 to correct the oscillator frequency, measured at the E coaxial output of the B541, to 1000 c/s ± 0.25 per cent.

(5) Check that variation of the Cal Zero control to its maximum travel on either side of the mid position varies the oscillator frequency by ± 15 c/s from 1000 c/s. If necessary, adjust capacitor C5 to obtain this frequency swing.

(6) Check the amplitude of oscillation on each capacitance range from x 1 pF to x 1.0μF. The amplitude of oscillation should be 60V on the x 1 pF range and should decrease in a decade relationship, within ± 0.1 per cent, to 60mV on the x 1.0μF range.

Amplifier gain

(7) Select the x 0.1μF range.
(8) Disconnect the feedback and output leads at the emitter of transistor VT7 and connect an oscilloscope between the emitter and chassis.
(9) Stop oscillations by putting a short circuit across R3.
(10) Apply a 17 mV r.m.s. signal at 1000 c/s through a 1000 pF ± 1 per cent capacitor to the inner lead from the I socket on the B541.
(11) Adjust the applied frequency to get maximum output on the oscilloscope. The amplitude of the output should be more than 500 mV peak to peak. If the gain is below the required level, check the voltages, using the table on p. 19 to locate the fault.
(12) Reconnect the amplifier feedback and output leads and remove the short circuit across R3.

Checking the standard (C6, C7)

(13) Select the x 0.1μF range.
(14) Connect a low loss polystyrene capacitor of value 0.1μF ± 0.1 per cent between the inner leads from the E and I sockets on the B541.
(15) Select a decade reading of 10.
(16) Press both left hand buttons whilst adjusting the Cal Zero knob for zero meter reading. Release the buttons.
(17) Press the Cal FSD button and adjust the associated control knob for full scale reading on the meter. Release the button.
(18) Read the capacitance. If the value is not within ±0.1 per cent of 0.1μF adjust capacitor C7 to correct the bridge.
(19) Turn the decade switch fully counterclockwise.
(20) Remove the 0.1μF polystyrene capacitor.

Checking the frequency adjustment of source and detector

(21) Join the outers of the leads from the E and I sockets of the B541.
(22) Connect an oscilloscope to the collector of transistor VT 13.
(23) Select a decade reading of 1.
(24) Press the Cal FSD button (S4) and adjust RV4 for minimum output and the Cal Zero control RV1 for zero output on the oscilloscope.
(25) Check that the Cal Zero control is within its range. If this condition is not satisfied, bad frequency adjustment of the source to the detector is indicated. If necessary, repeat items 3 to 5.

Power factor adjustment

(26) Select a range reading of x 0.001μF and a decade reading of 10.
(27) Connect a low loss polystyrene capacitor of 0.01μF to the inner leads from the E and I sockets of the B541.
(28) With Cal FSD switch (S4) depressed, adjust the Cal FSD control RV2 to give full scale deflection on the meter. Release S4.
(29) Press the Read Dissipation button (S6) and adjust the Cal Dissipation control (RV5) to give minimum output on the oscilloscope (connected to the collector of VT 13). Release S6.
(30) Press the Cal Dissipation switch (S5) and check that the meter reads within one per cent of full scale deflection. Release S5.
(31) Repeat item 28.
(32) Adjust RV3 to give minimum effect on the meter reading when the Cal Dissipation control (RV5) is varied. When properly adjusted, off-setting RV5 to give a 1V peak to peak signal on the oscilloscope should not affect the meter zero by more than one per cent of full scale deflection.
(33) Repeat item 28.
(34) Disconnect the oscilloscope.

(35) Connect a low loss polystyrene capacitor of 0.01μF ± 0.1 per cent in series with a high stability carbon resistor of 1592 ohms to the inner leads from the E and I sockets on the B541. This combination gives a power factor of 0.1

(36) Press the Read Dissipation switch S6 and adjust RV6 to give full scale deflection on the meter, i.e. full scale deflection for 0.1 power factor.

APPENDICES

Note: In Appendices 1 to 3 it is assumed that:

(1) the flux set up in the current transformer T4 by the feedback current I_o' is in such a sense as to oppose the flux set up by currents I_u, I_s and I_e.

(2) the gain of the amplifier is high, so that the resultant ampere turns in the secondary windings of current transformer T4 is practically zero and the amplifier input current is negligible compared with I_u, I_s and I_e.

(3) the output from the voltage transformer is assumed to be E volts per turn.

Appendix 1

Autobalance capacitance measurement (fig 4b)

The resultant ampere turns in windings SEC1, SEC2 and SEC3 of current transformer T4 is zero:

$$\therefore \quad I_u N_u + I_s N_s = I_o' N_o$$

where I_u is current through unknown admittance Y_u
I_s " " " standard " Y_s
I_o' " current in feedback winding SEC3 of current transformer T4
N_u " high gain amplifier output current and $I' = cI_o$ where c is a constant
N_u " number of turns selected on winding SEC1 of current transformer T4
N_s " " " " " " SEC2 " " " "
N_o " " " " " " SEC3 " " " "

But $I_u = E_u Y_u$ and $I_s = E_s Y_s$

Where E_u is voltage across unknown ratio arm
E_s " " " the standard " "
E_o " amplifier output voltage
Z_o " " " impedance

$$\therefore \quad E_u Y_u N_u = E_s Y_s N_s + I_o' N_o$$

$$\text{i.e. } Y_u = E_s Y_s \frac{N_s}{E_u N_u} + \frac{cE_o}{Z_o} \frac{N_o}{E_u N_u}$$

Thus the unknown admittance Y_u is given by the sum of two terms. The first term on the right hand side of the equation is determined by the settings of the range and decade switches and provides an approximate value for Y_u. The second term on the right hand side of the equation determines the meter M1 reading.

Appendix 2

Example of autobalance capacitance measurement

2.1. Setting up the circuit (fig. 3b)

Suppose the x 100pF range is selected, the decade switch is set to display the digit 6· and the Cal FSD switch is depressed, as shown in fig. 3b. The resultant ampere turns in windings SEC2 and SEC3 of the current transformer T4 is zero.:

$$\therefore I_s N_s = I_o' N_o$$

but

$E_s = E$ $\quad N_s = 100$ turns $\quad I_s = E_s j\omega C_s$

$E_u = 0$ $\quad N_u = 100$ turns $\quad I_o' = cE_o/Z_o$

$N_o = 10$ turns

$$\therefore E j\omega C_s\ 100 = (CE_o/Z_o)10$$

and

$$cE_o = E(10 j\omega C_s Z_o) \quad \ldots\ldots 1$$

The phase sensitive detector is designed so that the meter deflection is $k_1 E_o$, where k_1 is a constant. In the setting up process, the detector circuit output is adjusted by the Cal FSD control RV2 for full scale deflection on meter M1, i.e. 10. Therefore from equation 1:

$$10 = k_1 E(10 j\omega C_s Z_o)/c$$

i.e.

$$k_1 = c/E j\omega C_s Z_o$$

and meter deflection $= cE_o/E j\omega C_s Z_o \quad \ldots\ldots 2$

2.2. Capacitance measurement with autobalance and no decade (fig. 4a)

The decade switch S2 is set fully counterclockwise and the range switch S1 is adjusted for an on scale meter M1 reading. Suppose this requires the x100pF setting of the range switch. The resultant ampere turns ir windings SEC1 and SEC3 of current transformer T4 is zero:

$$\therefore I_u N_u = I_o' N_o$$

But

$E_s = 0$ $\quad N_s = 100$ $\quad I_u = E_u j\omega C_u$

$E_u = 100E$ $\quad N_u = 100$ $\quad I_o' = cE_o/Z_o$

$N_o = 100$

$$\therefore j\omega C_u = cE_o/10^2 EZ_o \quad \ldots\ldots 3$$

Suppose, for example, the meter reading is approximately 6.45, then from equation 2:

$$6.45 = cE_o/E j\omega C_s Z_o \quad \ldots\ldots 4$$

Substituting equation 4 in equation 3 gives:

$$C_u = 6.45 C_s \times 10^{-2}$$

But

$C_s = 0.01\mu F$

$C_u = 6.45 \times 10^{-4}\mu F$

$= 6.45 \times 100pF$ $\quad \ldots\ldots 5$

i.e.

$C_u = 645pF$

2.3. Capacitance measurement using decade and autobalance (fig. 4b)

Since the meter cannot indicate accurately three significant figures, the decade switch is advanced to read the first digit of the unknown capacitance, i.e. until 6. appears in the left hand window. The resultant ampere turns in windings SEC1, SEC2 and SEC3 of T4 is zero:

$$\therefore \quad I_u N_u + I_s N_s = I_o' N_o$$

But

$E_s = -6E$ $\quad N_s = 100$ $\quad (I_u = E_u j\omega C_u)$

$E_u = 100E$ $\quad N_u = 100$ $\quad (I_s = E_s j\omega C_s)$

$N_o = 10$ $\quad (I_o' = cE_o/Z_o)$

$$\therefore \quad j\omega C_u = (600 j\omega C_s + 10cE_o/EZ_o)/10^4 \ldots\ldots 6$$

The meter now shows the second and third digits of the unknown capacitance value. Suppose the meter reading is 4.3 showing that the second and third digits of the capacitance value are 4 and 3, then from equation 2:

$$4.3 = cE_o/Ej\omega C_s Z_o \ldots\ldots 7$$

Substituting equation 7 in equation 6 gives:

$$C_u = 6.43 C_s \times 10^{-2}$$

$$\left.\begin{aligned} C_u &= 6.43 \times 10^{-4}\mu F \\ C_u &= 6.43 \times 100 pF \\ C_u &= 643 pF \end{aligned}\right\} \ldots\ldots 8$$

Appendix 3

B541 as a differential bridge or comparator

Suppose an external comparator standard C_e is connected into the transformer ratio arm bridge as illustrated in the simplified typical circuit of fig.8. The resultant ampere turns in windings SEC1, SEC2 and SEC3 of current transformer T4 is zero:

$$\therefore \quad I_u N_u + I_e N_e + I_s N_s = I_o' N_o$$

where

I_e = current through comparator standard admittance

N_e = number of turns selected on winding SEC1 of current transformer T4 associated with the comparator standard C_e

N_u = number of turns selected on winding SEC1 of T4 associated with the unknown capacitance C_u

and $I_u = E_u j\omega C_u$, $I_s = E_s j\omega C_s$, $I_e = E_e j\omega C_e$,

$I_o' = cE_o/Z_o$ = (meter deflection $x E j\omega C_s$) from equation 2, Appendix 2, p. 22.

$$\therefore \quad \frac{E_u N_u C_u + E_e N_e C_e + E_s N_s C_s}{N_o E C_s} = \text{meter deflection} \ldots\ldots 9$$

With the decade switch turned fully anticlockwise so that no decade digit is displayed in the left hand window:

$E_e = -10E$ $\quad N_e = 100$ $\quad (C_s = 0.01\mu F)$

$E_s = 0$ $\quad N_o = 100$ (S2 at position 0)

$N_s = 100$

Symbols as p. 21 and E_e = voltage across comparator arm (C_e).

By substituting these values and the values for E_U and N_U at each range setting in equation 9 above, the meter deflections obtained can be calculated in terms of the values of the comparator standard $C_e(\mu F)$ and the capacitor being measured $C_U(\mu F)$, see column 4 of the following table.

Range	Full scale deflection	Values	Meter deflection
x 1pF	10pF	$E_U = 1000\,E$ $N_U = 1000$	$10^6 C_U - 10^3 C_e$
x 10pF	100pF	$E_U = 100E$ $N_U = 1000$	$10^5 C_U - 10^3 C_e$
x 100pF	1000pF	$E_U = 100E$ $N_U = 100$	$10^4 C_U - 10^3 C_e$
x 0.001μF	0.01μF	$E_U = 10E$ $N_U = 100$	$10^3 C_U - 10^3 C_e$
x 0.01μF	0.1μF	$E_U = 10\,E$ $N_U = 10$	$10^2 C_U - 10^3 C_e$
x 0.1μF	1μF	$E_U = E$ $N_U = 10$	$10 C_U - 10^3 C_e$
x 1.0μF	10μF	$E_U = E$ $N_U = 1$	$C_U - 10^3 C_e$

C_U and C_e in μF

COMPONENTS LIST

Capacitance Bridge B541

Resistors

Reference	Value	Per Cent Tolerance	Description	Manufacturer's Name	Manufacturer's Type
R1	22K	±10	Fixed	Morgan[1]	S
R2	6.8K	±10	"	"	"
R3	10K	±10	"	"	"
R4	3.9K	±10	"	"	"
R5	3.9K	±10	"	"	"
R6	1.2K	±10	"	"	"
R7	47Ω	±10	"	"	"
R8	47K	±10	"	"	"
R9	560Ω	±10	"	"	"
R10	390Ω	±10	"	"	"
R11	150Ω	±10	"	"	"
R12	15K	±10	"	"	"
R13	1.8K	±10	"	"	"
R14	10K	±10	"	"	"
R15	1.8K	±10	"	"	"
R16	4.7K	±10		"	"
R17	1.5K	±10	"	"	"
R18	1.8K	±10	"	"	"
R19	15K	±10	"	"	"
R20	10K	±10	"	"	"
R21	1.8K	±10	"	"	"
R22	2.7K	±10	"	"	"
R23	680Ω	±10	"	"	"
R24	270Ω	±10	"	"	"
R25	100Ω	±10	"	"	"
R26	12K	±10	"	"	"
R27	12K	±10		"	"
R28	22K	±10	"	"	"
R29	22K	±10	"	"	"
R30	3.3K	±10	"	"	"
R31	680Ω	±10	"	"	"
R32	1.2K	±10	"	"	"
R33	1.5K	±2	¼W h.s[2]	Painton	72
R34	560Ω	±10	Fixed	Morgan[1]	S
R35	1.5K	±2	¼W h.s.	Painton	72
R36	4.7K	±10	Fixed	Morgan[1]	S
R37	4.7K	±10	"	"	"
R38	18K	±2	¼W h.s.	Painton	72
R39	8.2K	±2	"	"	"
R40	3.9K	±10	Fixed	Morgan[1]	S
R41	5.6K	±10	"	"	"
R42	18K	±2	¼W h.s.	Painton	72
R43	2.2K	±10	Fixed	Morgan[1]	S
R44	5.6K	±10	"	"	"
R45	820Ω	±10	"	"	"
R46	3.3K	±10	"	"	"
R47	8.2K	±10	"	"	"
R48	1K	±2	¼W h.s.	Painton	72
R49	22K	±2	"	"	"
R50	10K	±10	Fixed	Morgan[1]	S
R51	10K	±10	"	"	"
R52	3.9K	±10	"	"	"
R53	4.7K	±10	"	"	"
R54	12K	±10	"	"	"
R55	12K	±10	"	"	"
R56	47Ω	±10	"	Erie	16
R57	100K	±2	"	Painton	72

Potentiometers

Reference	Value	Description	Manufacturer's Name	Manufacturer's Type
RV1	25K	Variable	Plessey	E
RV2	2.5K	"	"	"
RV3	10K	"	"	M.P.
RV4	10K	"	"	"
RV5	5K	"	"	E
RV6	22K	"	"	"

Capacitors

Reference	Value	Per Cent Tolerance	Description	Manufacturer's Name	Manufacturer's Type
C1	64μF	+50-10	Electrolytic	Mullard	C426AE/D64
C2	100μF	"	"	"	C426CE/B100
C3	100μF	"	"	"	"
C4	0.1μF	±1	Polystyrene 125V	Salford	PF
C5	2000pF	±10	Silver Mica A.I.C.	T.C.C.	425 SMP
	3000pF	±10	"	"	501 SMP
C6	0.01μF	-1+0	200V	Johnson Matthey	C55W
C7	3-30pF		Trimmer	Mullard	
C8	3-30pF	±1	"	"	
C9	7000pF	±1	150V	Salford	D.F.
C10	2500μF		Electrolytic	Hunts	L37/1MEF106/T
C11	64μF	+50-10	"	Mullard	C426CED64
C12	2μF	+100-10	"	"	C426AD/D2
C13	64μF	+50-10	"	"	C426CE/D64
C14	0.01μF		Paper	"	C280AA/P10K
C15	64μF	+50-10	Electrolytic	"	C426CE/D64
C16	0.1 μF	±1	Polystyrene 125V	Salford	P.F.T.
C17	160μF	+50-10	Electrolytic	Mullard	C426CE/D160
C18	1.25μF	+100-10	"	"	C426AD/E125
C19	64μF	+50-10	"	"	C426CE/D64
C20	25μF	+50-10	"	"	C426CE/F25
C21	25μF	"	"	"	"
C22	64μF	+50-10	"	"	C426CE/D64
C23	0.02μF	±5	Polystyrene 150V	Salford	P.F.T.
C24	"	"	"	"	"
C25	"	"	"	"	"
C26	64μF		Electrolytic Min³	Mullard	C426AE/D64
C27	64μF	+50-10	Electrolytic	"	C426CE/D1160
C28	160μF	+50-10	Electrolytic	"	C426CE/D1160
C29	64μF	"	"	"	C426CE/D64
C30	2500μF			Hunts	L371MEF106/T

Transistors

Reference	Manufacturer's Name	Manufacturer's Type
VT1	Mullard	OC45
VT2	"	"
VT3	"	OC72
VT4	Brush Crystal Co.	OC305/2
VT5	"	"
VT6	"	"
VT7	"	"
VT8	"	"
VT9	S.T.C.	TK20C
VT10	"	"
VT11	Brush Crystal Co.	OC305/2
VT12	Mullard	OC44
VT13	"	"
VT14	"	OC45
VT15	"	OC139

Diodes

Reference	Manufacturer's Name	Manufacturer's Type
MR1	Mullard	OA200
MR2	"	"

Transformers

Reference	Description	Manufacturer's Name	Manufacturer's Type
T1	Oscillator coil with Vinkor adjustable pot core	Mullard	Coil former DT2012 Pot Core LA2100
T2	Toroidal	Wayne Kerr	
T3	Not used.		
T4	Toroidal	"	
T5	Oscillator coil with Vinkor adjustable pot core	Mullard	Coil former DT2012 Pot Core LA2100
T6		Ardente	D332/WT

Miscellaneous

Reference	Component	Manufacturer's Name	Manufacturer's Type
N1	Neon Stabiliser	Hivac	CU2213
TH1	Thermistor	S.T.C.	24
S1	Rotary switch, 3 section, 8 position	AB Metal Prod Ltd.	
S2	" " 4 " 11 "	"	
S3	Microswitch, gold plated contacts	Carr Fastener	81/656
S4	"	"	"
S5	"	"	"
S6	"	"	"
M1	Meter	Pullin	

Power Supply PS109

Resistors

Reference	Value	Per Cent Tolerance	Description	Manufacturer's Name	Manufacturer's Type
R1	470Ω	±10	Fixed	Morgan[1]	S
R2	1.2K	±10	"	"	"
R3	18K	±10	"	"	"
R4	1.2K	±10	"	"	"
R5	2.2K	±10	"	"	"
R6	39K	±10	"	"	"
R7	22K	±10	"	"	"
R8	56Ω	±10	"	"	"
RV1	4.7K		Variable	Plessey	CP 404/1 0014/427A

Capacitors

Reference	Value	Description	Manufacturer's Name	Manufacturer's Type
C1	64μF	Electrolytic	Mullard	C426CE/F64
C2	64μF	"	"	"
C3	64μF	"	"	"
C4	64μF	"	"	C426CE/G64

Transistors

Reference	Manufacturer's Name	Manufacturer's Type
VT 1	Mullard	OC205
VT 2	Brush Crystal Co.	OC305/2
VT 3	"	"
VT 4	Mullard	OC201

Diodes

Reference	Manufacturer's Name	Manufacturer's Type
MR1 (Zener)	Mullard	OAZ201
MR2 (Silicon)	Texas Instruments	15131
MR3 (")	"	"
MR4 (")	"	"
MR5 (")	"	"

Transformer

Reference	Type	Manufacturer's Name	Manufacturer's Type
T1		Ardente	D8085/WT

Miscellaneous

Reference	Component	Manufacturer's Name	Manufacturer's Type
FS1	Mains plug	Bulgin	P429
"	Fuse 10mA, 230V	Belling Lee	L754, Size 00
	" 25mA, 115V	"	"

Recorder Panel RP541

Resistors

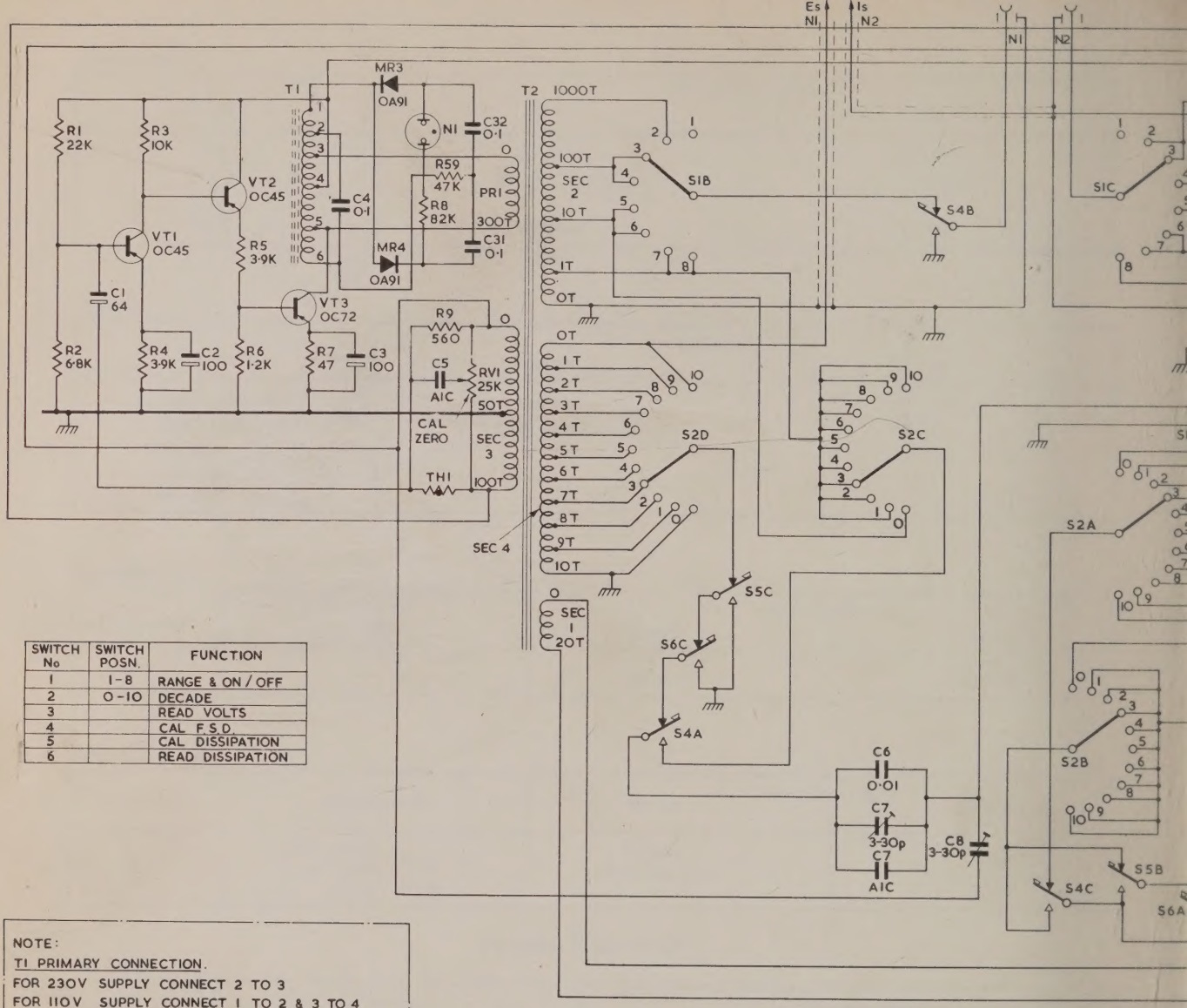
Reference	Value	Per Cent Tolerance	Description	Manufacturer's Name	Manufacturer's Type
R1	180Ω	±5	Fixed	Morgan [1]	S
R2	18K	±5	"	"	"
RV1	10K		Variable	Reliance	WL35

Miscellaneous

Reference	Component	Manufacturer's Name	Manufacturer's Type
S1	Switch, 1 section, 3 pole, 3 position	AB metals	
J1	Jack socket	Igranic	P73
SK1	Moulded BNC	Greenpar	GE350 39X
SK2	"	"	"

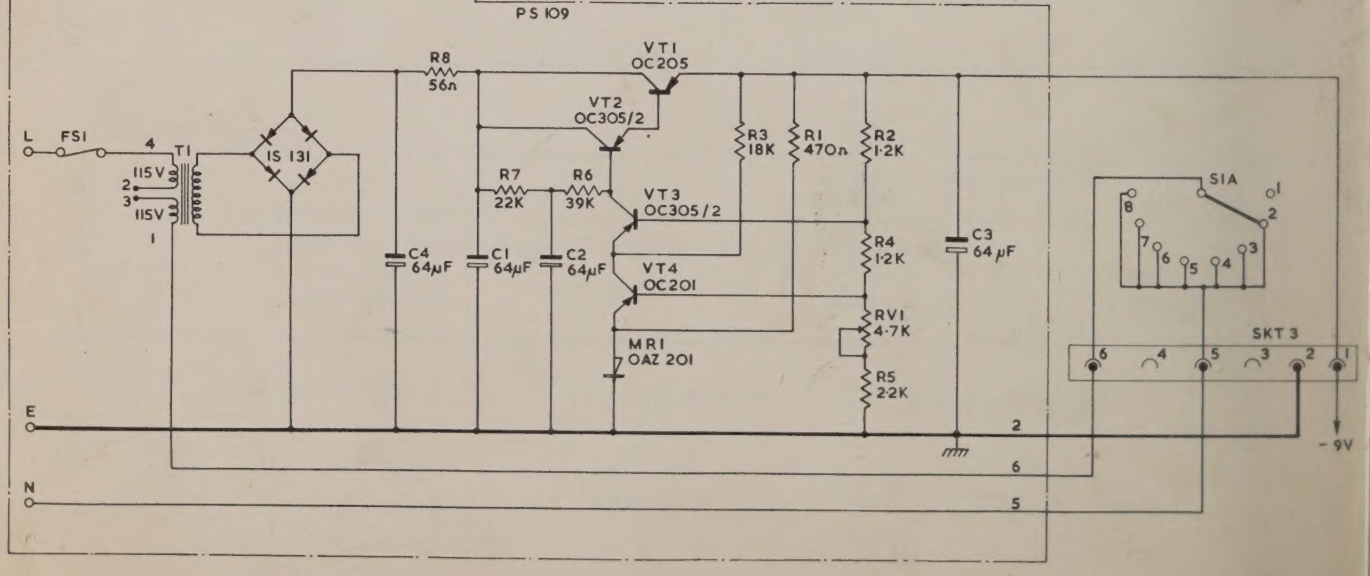
1 or Erie RMA16 2 h.s. = high stability 3 min. = miniature

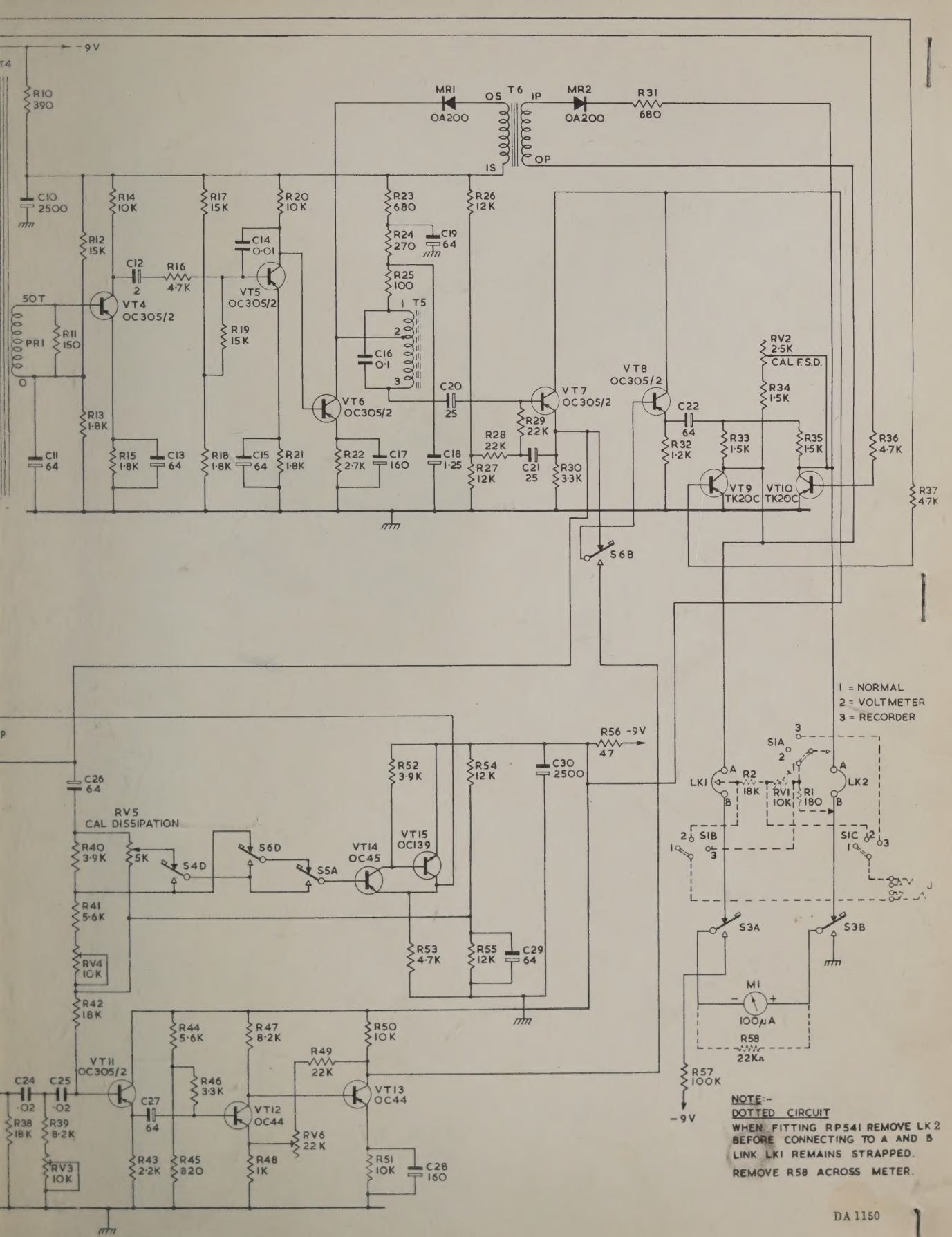
LEADS TYPE. BM23 LOW CAP TYPE LCC3 6 pin



SWITCH No	SWITCH POSN.	FUNCTION
1	1-8	RANGE & ON / OFF
2	0-10	DECADE
3		READ VOLTS
4		CAL F.S.D.
5		CAL DISSIPATION
6		READ DISSIPATION

NOTE:
T1 PRIMARY CONNECTION.
FOR 230V SUPPLY CONNECT 2 TO 3
FOR 110V SUPPLY CONNECT 1 TO 2 & 3 TO 4





DA 1150

DIAGRAM (D11150/V)

MP MASTER
MA33076

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